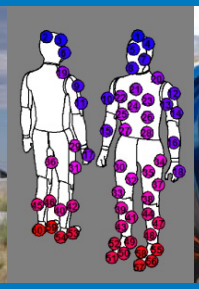
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Electric Drive Vehicle Climate Control Load Reduction


Task Leader: John P. Rugh
P.I. & Presenter: Matthew A. Jeffers
National Renewable Energy Laboratory
June 9, 2015

2015 VTO Annual Merit Review and Peer Evaluation Meeting Project ID: VSS097

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Overview

Timeline

Project start date: **FY12**
Project end date: **FY15**
Percent complete: **85%**

Barriers

- **Range** – impact of climate control on range
- **Cost** – cost premium for electric drive vehicles (EDVs)
- **Life** – battery life impacted by temperature

Budget

Total project funding (to date): **$3,350K**
Funding received in FY14: **$900K**
Funding for FY15: **$750K**
Partner in-kind cost share: **$225K***

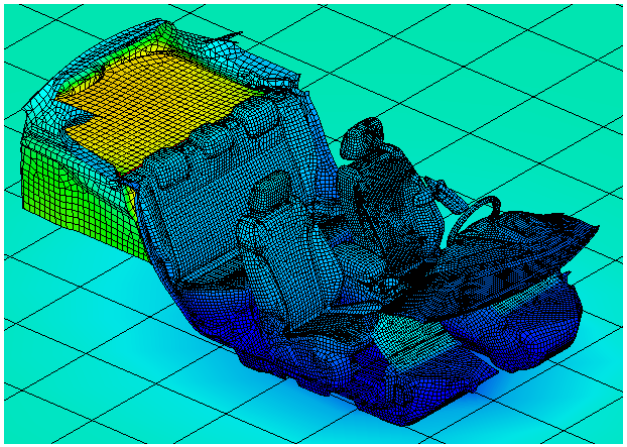
*** Not included in total**

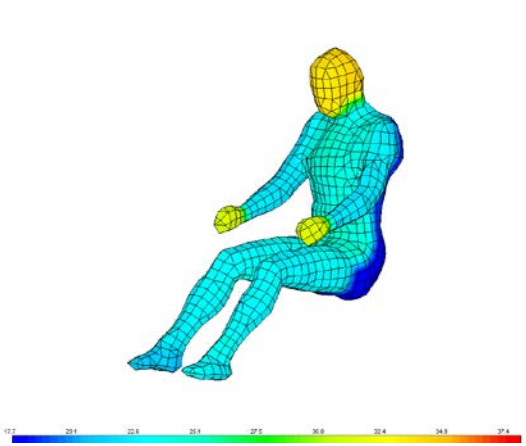
Partners

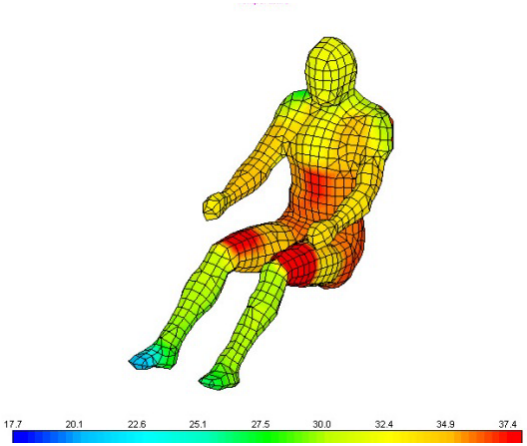
- Interactions/Collaborations:
  - Ford
  - Measurement Technology Northwest (MTNW)
  - ThermoAnalytics, Inc.
  - Gentherm
  - Eastman Chemical (Solutia)
  - Argonne National Laboratory (ANL)
- Project Lead:
  - National Renewable Energy Laboratory (NREL)

Relevance – Overcoming Barriers to EDVs

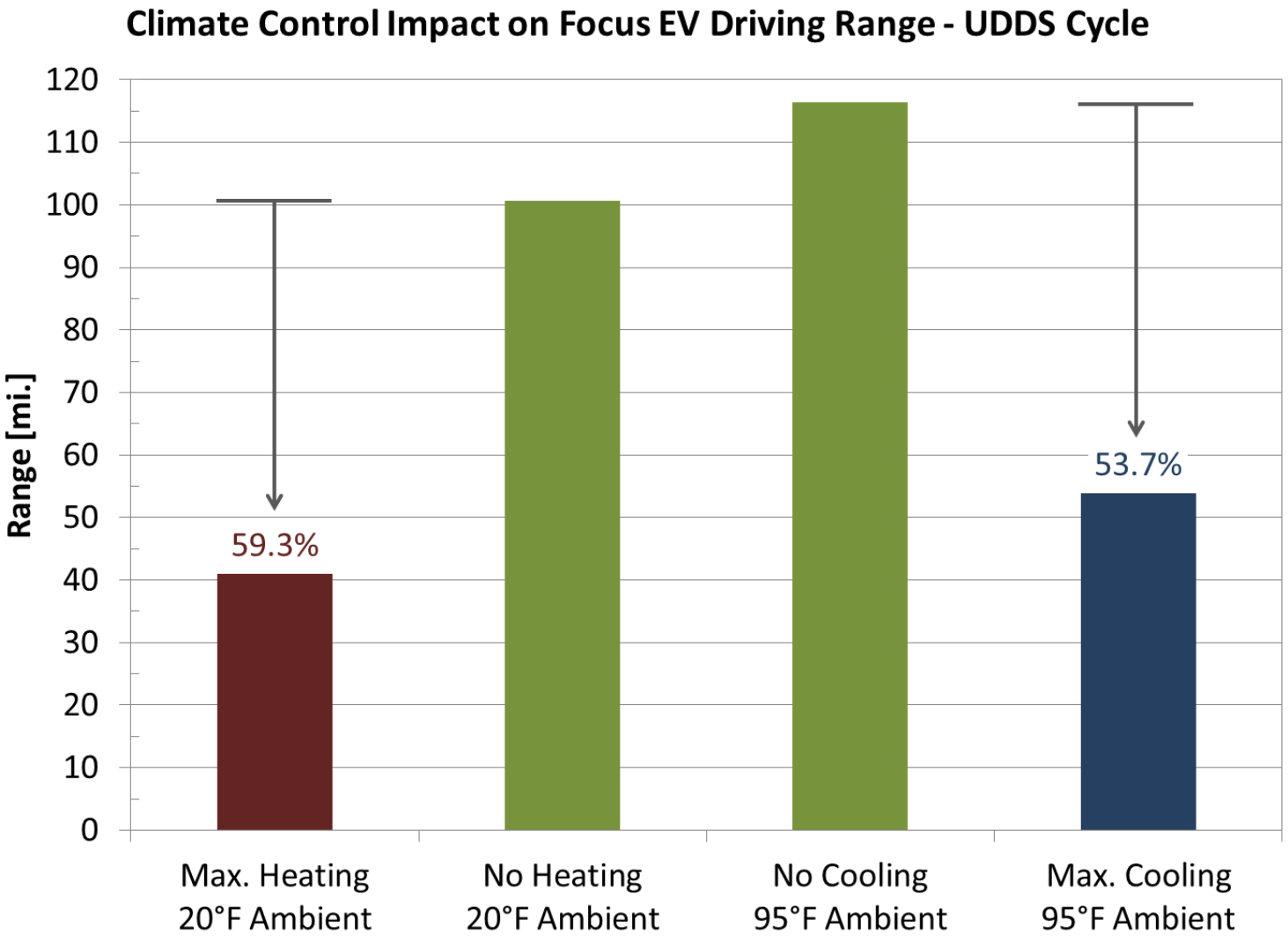
- **Range**
  - Reducing climate control energy requirements in warm and cold weather will improve real-world driving range and increase adoption of EDVs.
- **Cost**
  - Less stored energy required for climate control will enable smaller batteries for the same driving range, reducing electric vehicle cost and weight.
- **Life**
  - Improved cabin thermal management can help reduce battery degradation caused by high temperatures.
- **Thermal Comfort**
  - A focus on human thermal comfort is required for advanced climate control design.





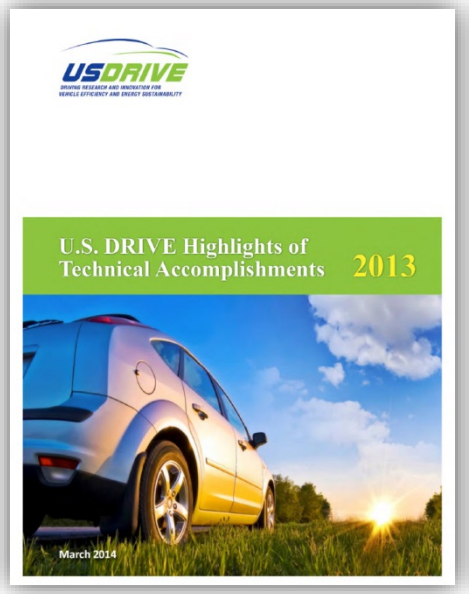


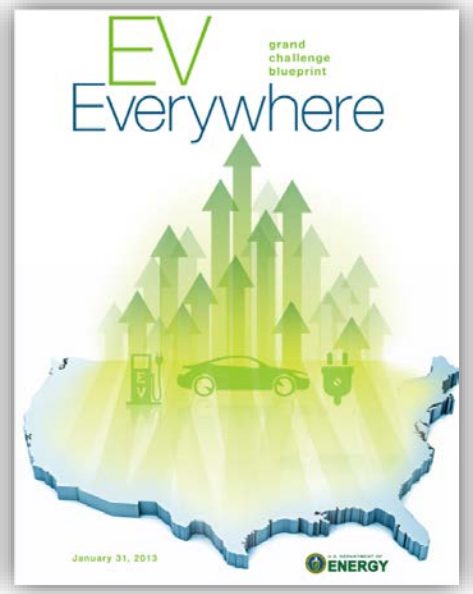
Relevance – Climate Control Impact on EDV Range

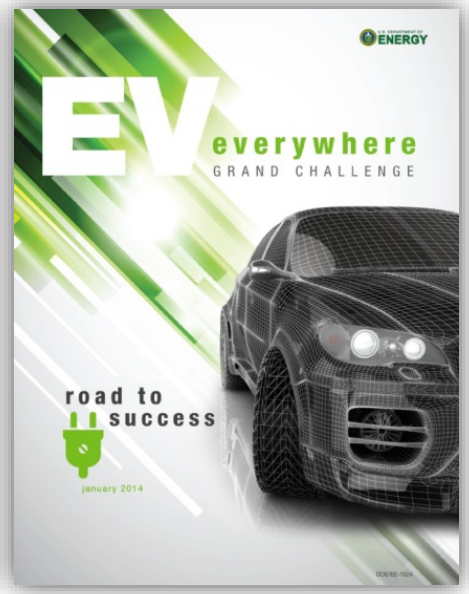


Source: Argonne National Laboratory's Advanced Powertrain Research Facility

Relevance – Support Broad VTO Efforts



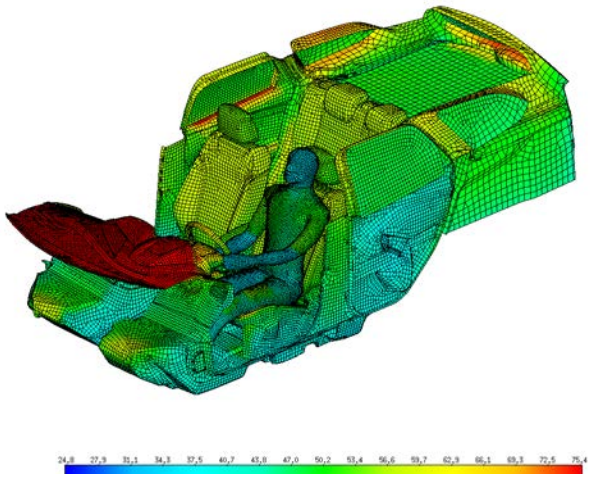




- **U.S. DRIVE Vehicle Systems Analysis Technical Team (VSATT)**
- **U.S. Department of Energy (DOE) Vehicle Technologies Office (VTO) Multi-Year Project Plan (MYPP)**
  - "…development of advanced vehicles and components to maximize vehicle efficiency…"
- **President's EV Everywhere Grand Challenge**
  - "EV Everywhere will focus on the following specific research areas:
    - Energy Load Reduction and Energy Management
    - Advanced HVAC Equipment
    - Cabin Pre-Conditioning"

Relevance – Objectives

- **Minimize the impact of climate control on grid-connected EDV range.**
  - Reduce vehicle thermal loads for heating and cooling.
  - Focus heating/cooling on occupants.
  - Develop a process to calculate range impact of HVAC energy savings.
- **Improve techniques for occupant thermal comfort evaluation.**



- **Increase electric range by 10% during operation of the climate control system through improved thermal management.**
  - Maintain or improve occupant thermal comfort.

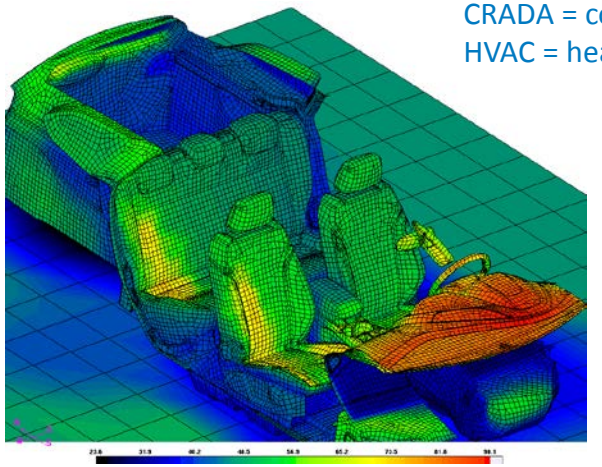
Approach – Milestones

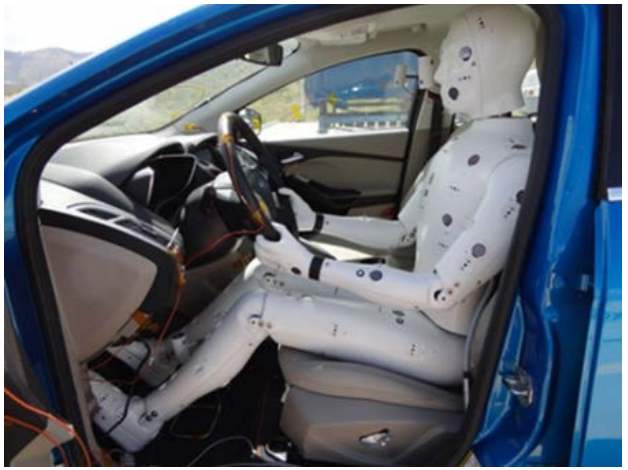
Month/Year	Description	Status
Q1 Dec. 2014	Milestone • Develop test plan and prepare vehicle configurations for cold weather outdoor thermal testing.	Complete
Q2 Mar. 2015	Milestone • Complete cold weather testing on the Focus Electric vehicles to assess zonal heating strategies.	Complete
Q3 June 2015	Milestone • Submit a presentation on the project and present at DOE's Annual Merit Review.	On Track
Q4 Sept. 2015	Milestone • Calculate the expected impact on EDV range and compare to 10% improvement goal. • Submit a progress summary of the task for the DOE annual report.	On Track

Approach

- **Coordinate closely with the auto industry to obtain relevant results that will impact the efficiency of future vehicles.**
  - Ford (CRADA partner), automotive suppliers, and developers of hardware/software tools for thermal comfort assessment.
- **Develop and evaluate strategies to reduce climate control loads in EVs.**
  - Conduct outdoor thermal tests to quantify thermal soak and transient heating/cooling impacts.
  - Perform thermal analyses to explore load reduction concepts and evaluate occupant thermal comfort.
- **Leverage results and resources from other DOE projects.**
  - Zonal climate control approach developed under thermoelectric HVAC projects.
  - Vehicle test data and models from other national laboratories.
- **Utilize and enhance thermal comfort evaluation tools to enable advanced HVAC design from an occupant thermal comfort perspective.**

CRADA = cooperative research and development agreement
HVAC = heating, ventilation and air conditioning





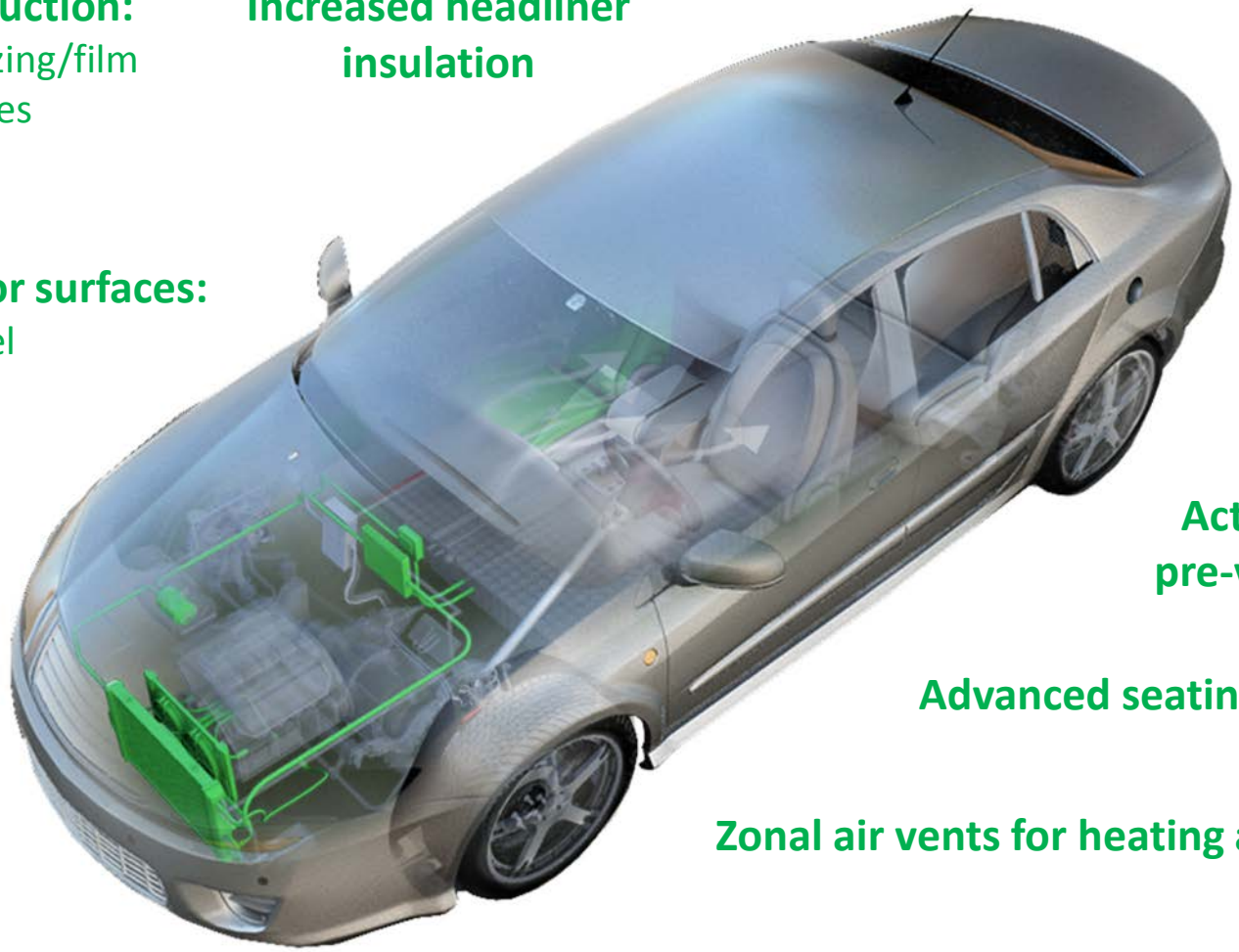
Approach – Focus Areas

Reduce Thermal Loads **Maintain or Improve Thermal Comfort**

Solar load reduction:
- Reflective glazing/film
- Window shades
- Cabin shading

Heated interior surfaces:
- Steering wheel
- Driver seat
- Floor mat

Increased headliner insulation



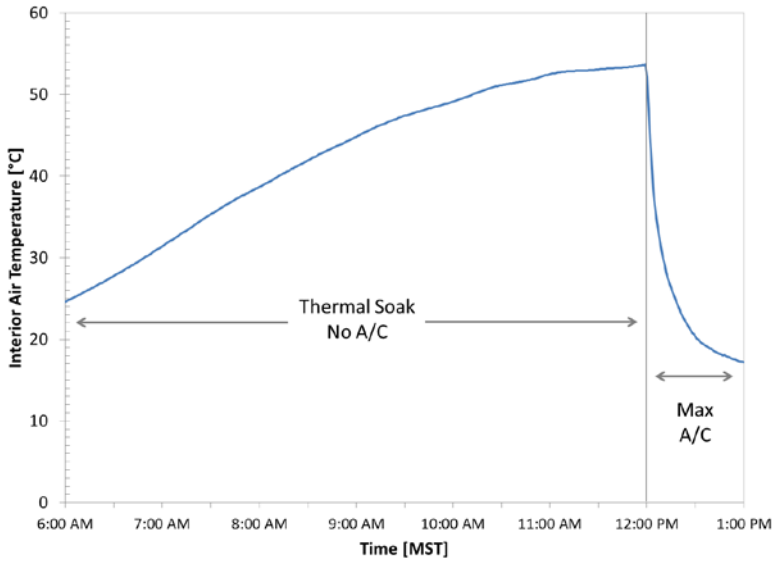
Active cabin pre-ventilation

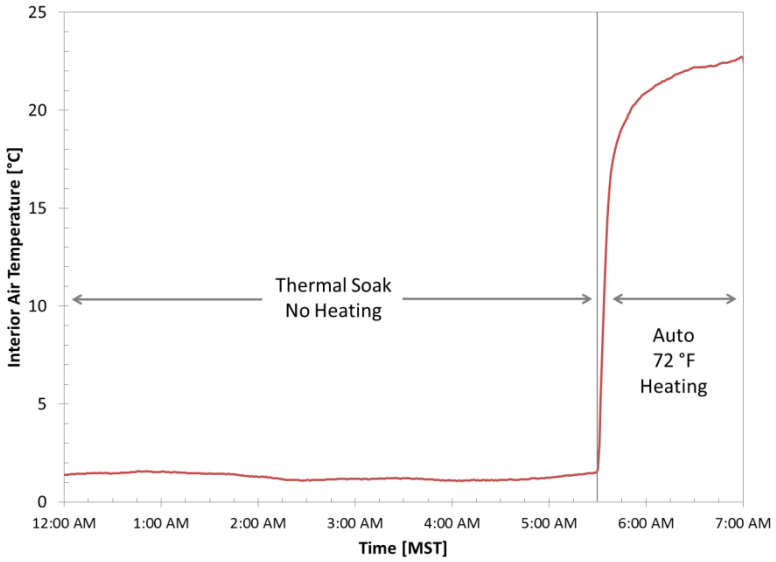
Advanced seating concepts

Zonal air vents for heating and cooling

Approach: Vehicle Testing

Warm and Cold Weather Outdoor Thermal Testing of EDVs at NREL





Accomplishments: Vehicle Testing – Cooling

Thermal Load Reduction Strategies to Decrease Solar Energy Stored in Cabin

Shading Canopy

- Entire vehicle shaded

White Film

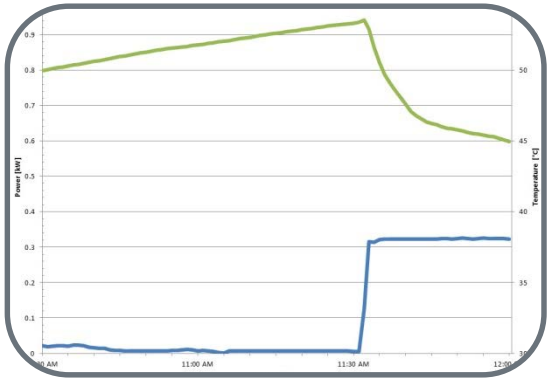
- Applied to all glazing

Solar-Reflective Film

- Applied to all glazing

Interior Air Temperature →

Blower Power →



Cabin Pre-Ventilation

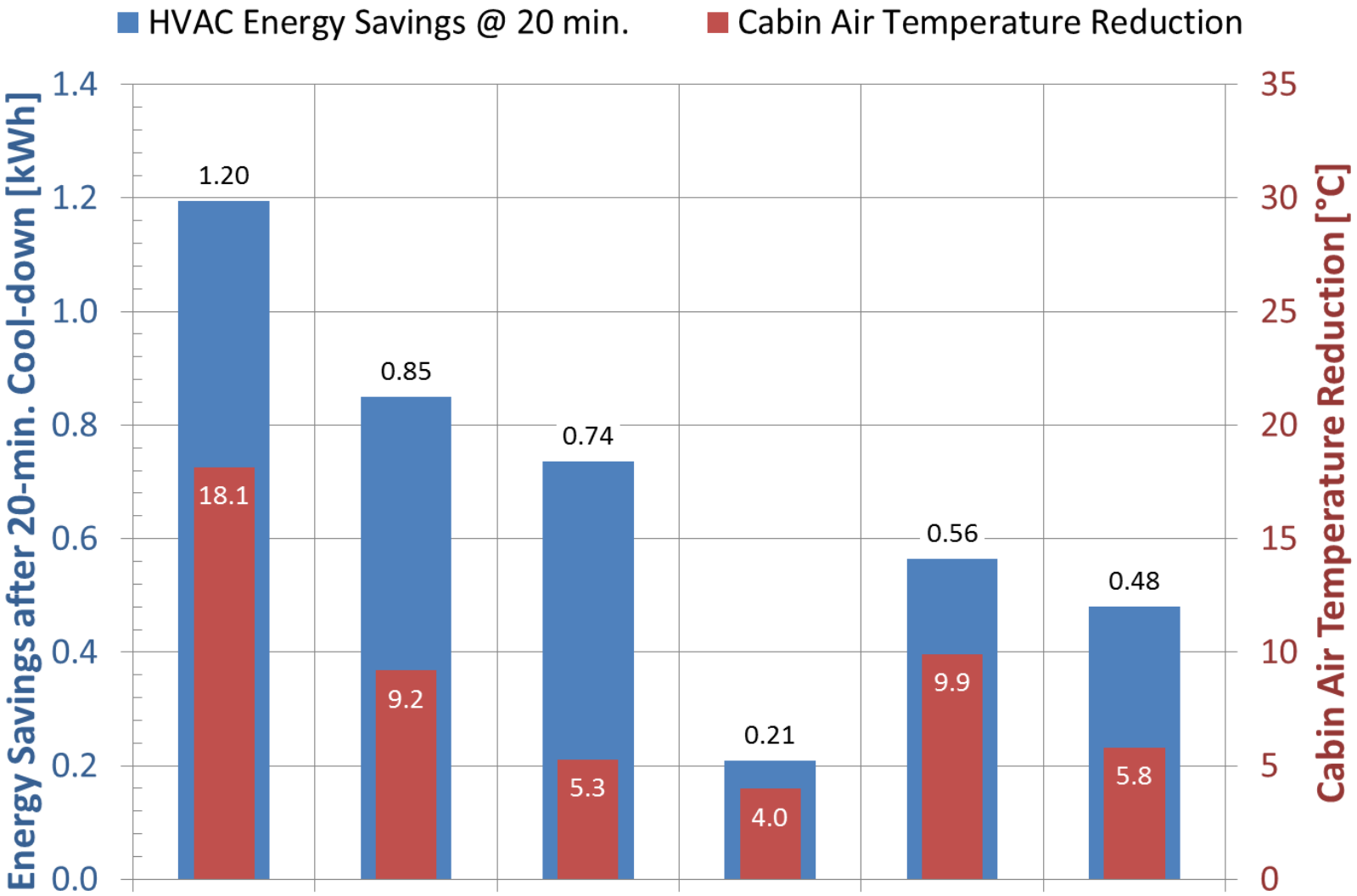
- Initiated before cool-down

IR-Reflective Windshield

- Windshield only

Accomplishments: Vehicle Testing – Cooling

Thermal Load Reduction Strategies Reduced Soak Temp. and A/C Energy Use



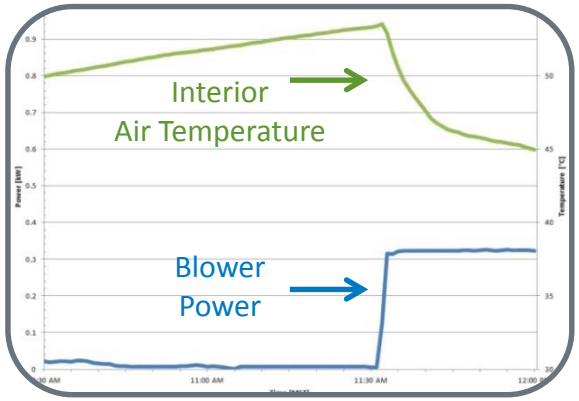
SR: solar-reflective
IRR: infrared-reflective
WS: windshield

Accomplishments: Vehicle Testing – Cooling

Thermal Load Reduction Strategies Combined with Zonal Air Flow

Cabin Pre-Ventilation

15 minutes before cool-down



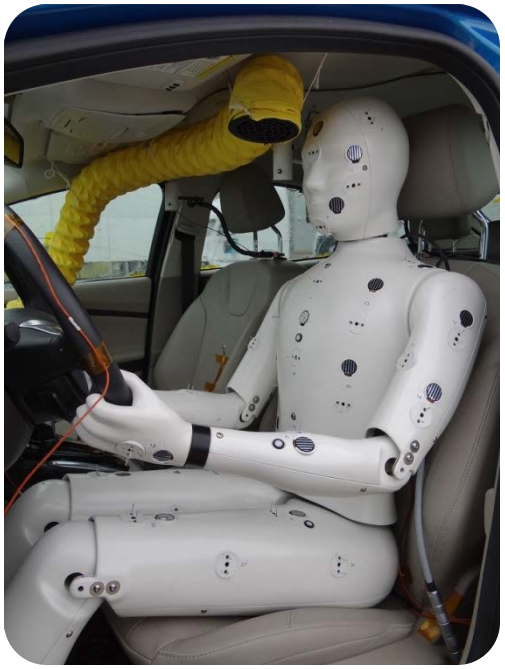
Solar Load Reduction

Solar-Reflective
Glazing Film

IR-Reflective
Windshield

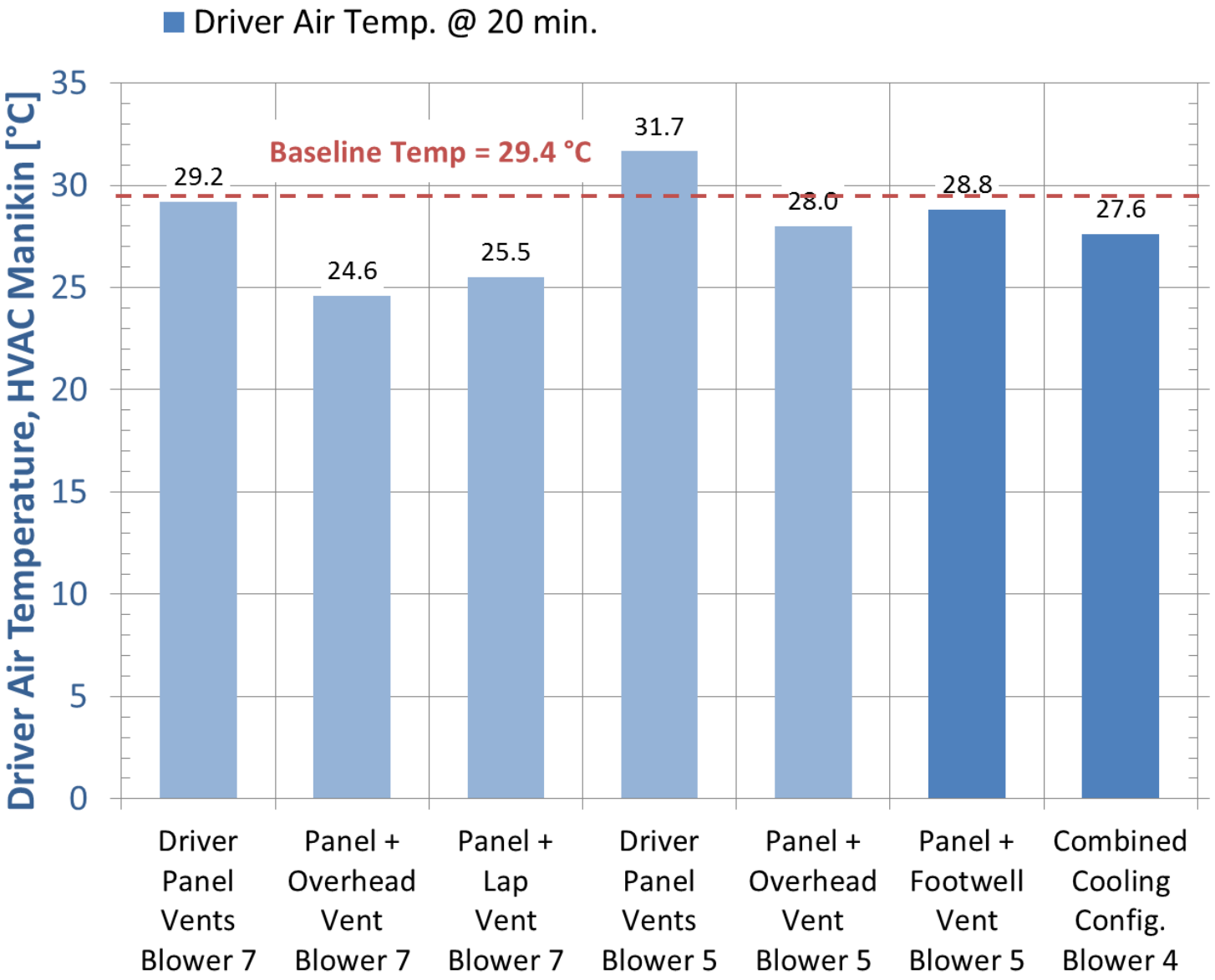
Zonal Air Flow

- Overhead vent
- Panel vent
- Foot vent



Accomplishments: Vehicle Testing – Cooling

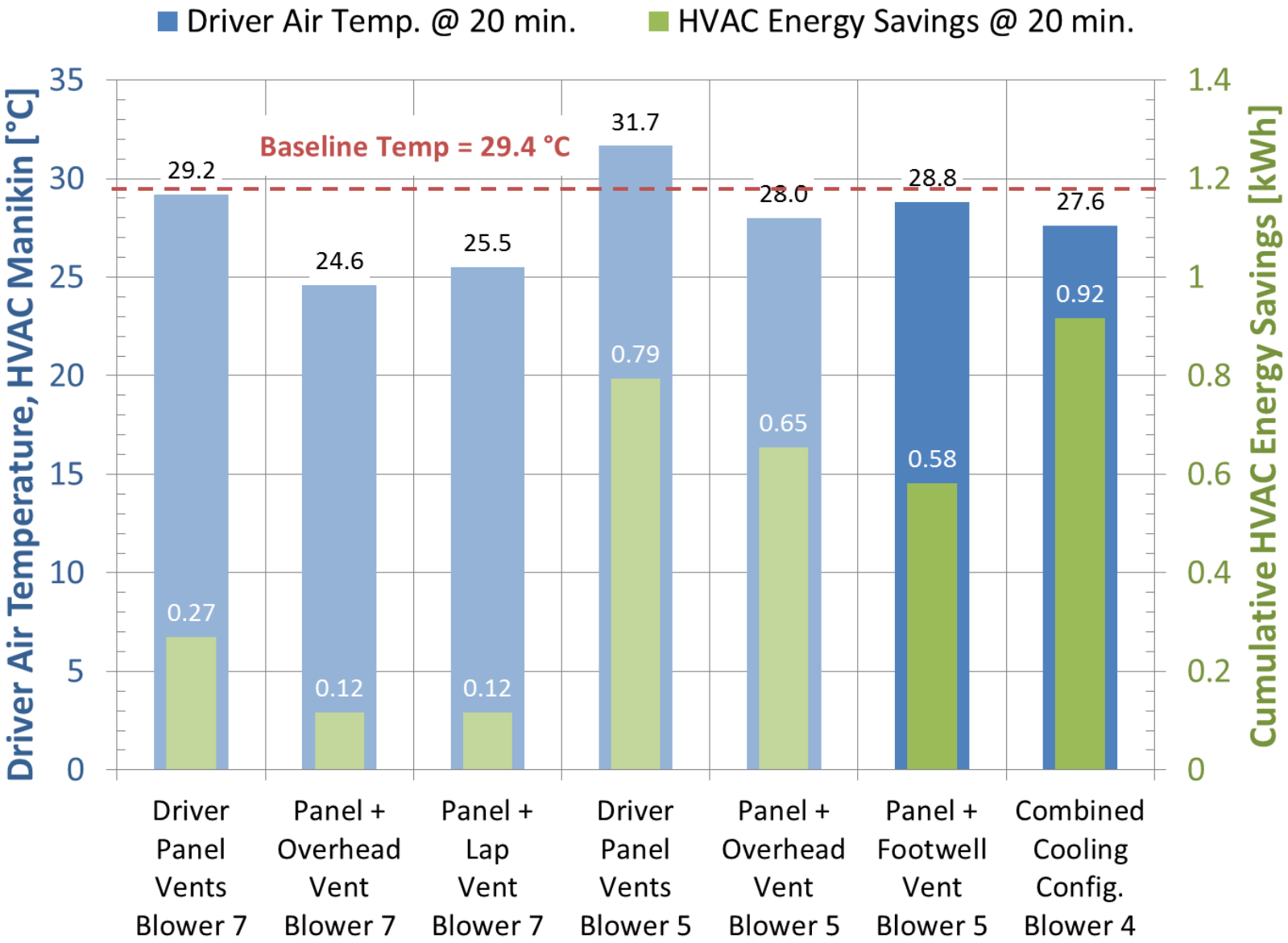
Zonal Configurations Had Lower Driver Air Temperatures and Lower Flow Rates



Accomplishments: Vehicle Testing – Cooling

Zonal Configurations Resulted in A/C Energy Savings

Maximum Potential Savings Case
1. Maximum A/C settings
2. Hot soak with solar load
3. Transient cool-down.

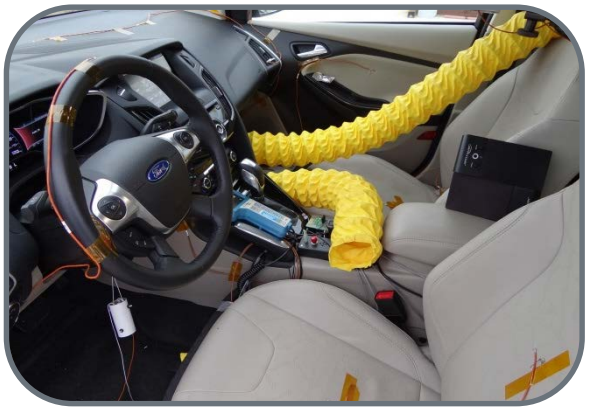


Accomplishments: Vehicle Testing – Heating

Zonal Heating Test Configurations Utilized Zonal Air Flow and Heated Surfaces

Zonal #1

- Driver vent only



Zonal #2

- Driver vent + lap vent

Zonal #3

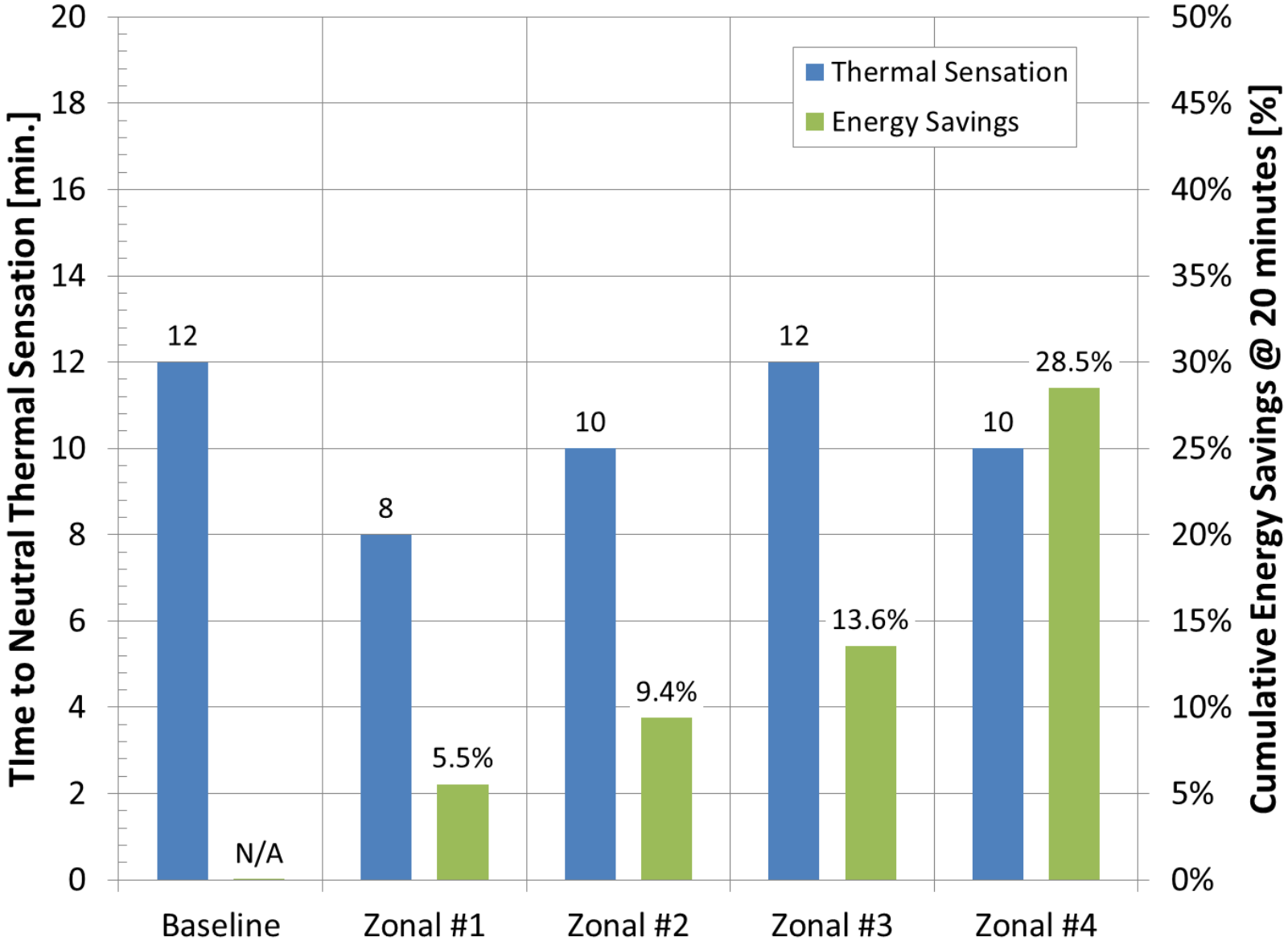
- Zonal driver vents + heated seat

Zonal #4

- Zonal driver vents + heated seat, steering wheel and floor mat

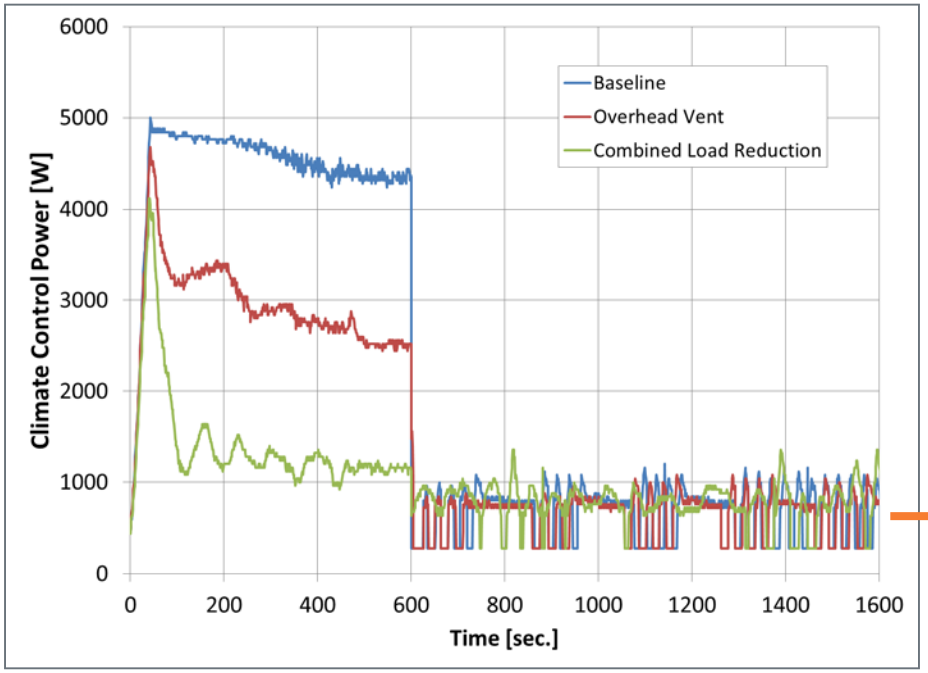
Accomplishments: Vehicle Testing – Heating

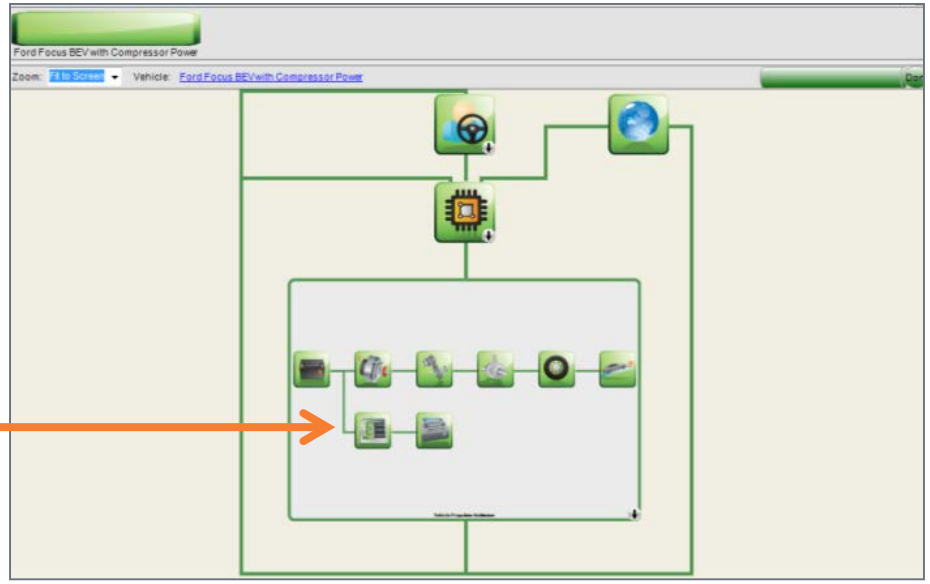
Zonal Heating Reduced HVAC Energy, Maintained Driver Thermal Sensation



Accomplishments: Vehicle Simulation – Range Impact

A/C Power from Testing Input into Focus Electric Autonomie Model



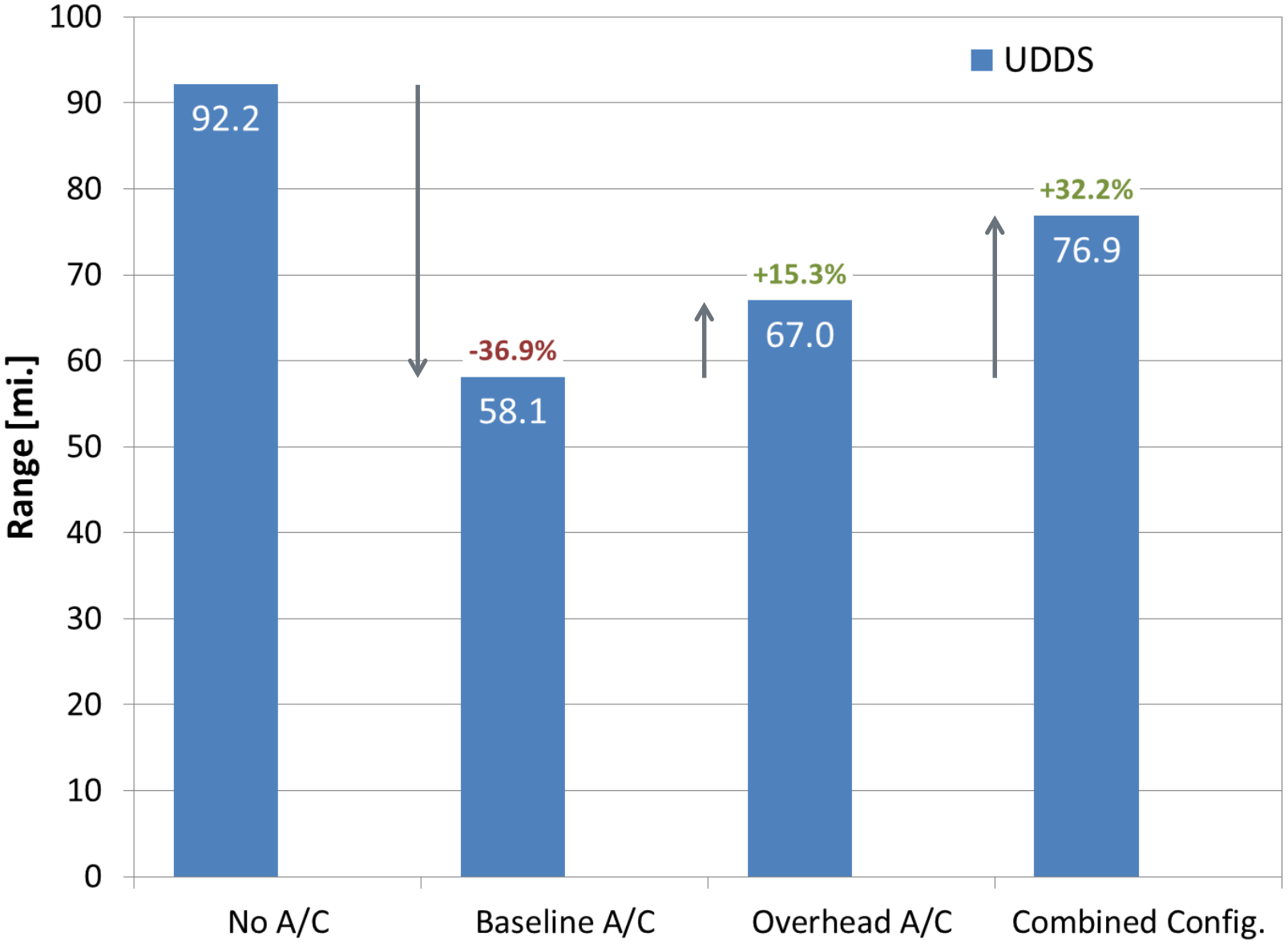


Measured compressor power

Autonomie Focus EV model

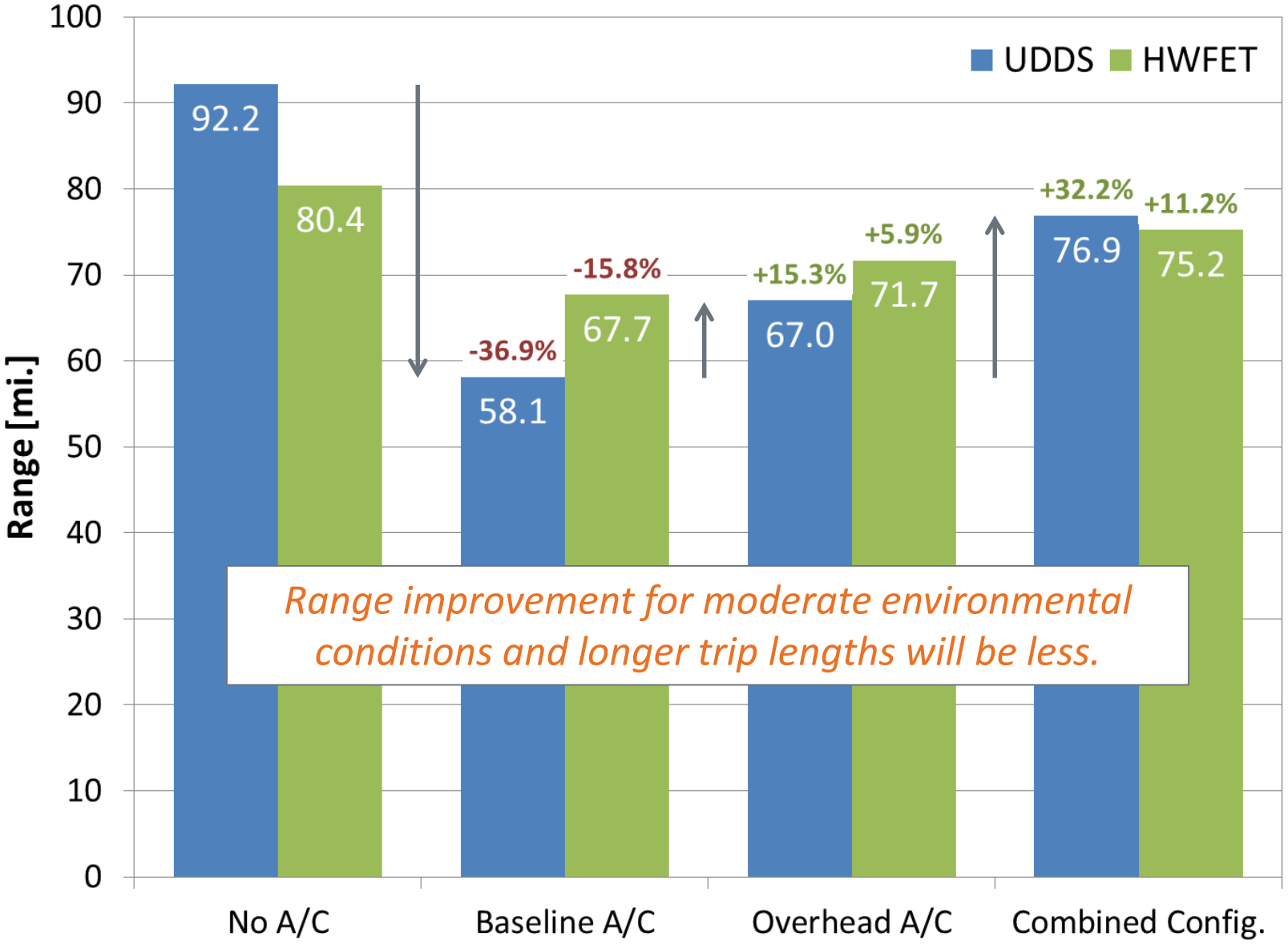
Accomplishments: Vehicle Simulation – Range Impact

Potential for Zonal Climate Control to Improve EV Range



Accomplishments: Vehicle Simulation – Range Impact

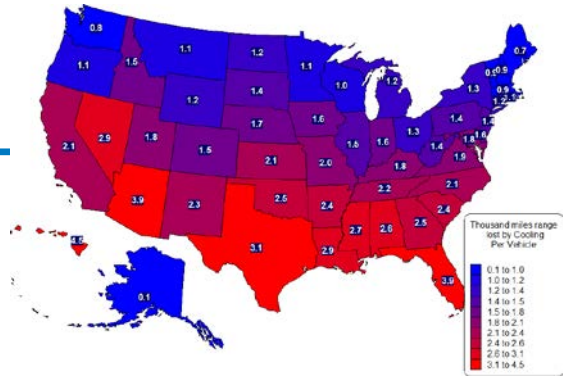
Potential for Zonal Climate Control to Improve EV Range



Collaboration and Coordination

- **Automotive Industry**
  - Ford – CRADA partner
  - Gentherm
  - Eastman Chemical (Solutia)
- **Thermal Manikin**
  - Measurement Technology Northwest
- **Software**
  - ThermoAnalytics, Inc.
- **DOE VTO Crosscutting**
  - John Fairbanks – leveraging thermoelectric research
- **National Lab Crosscutting**
  - ANL – vehicle model and test data

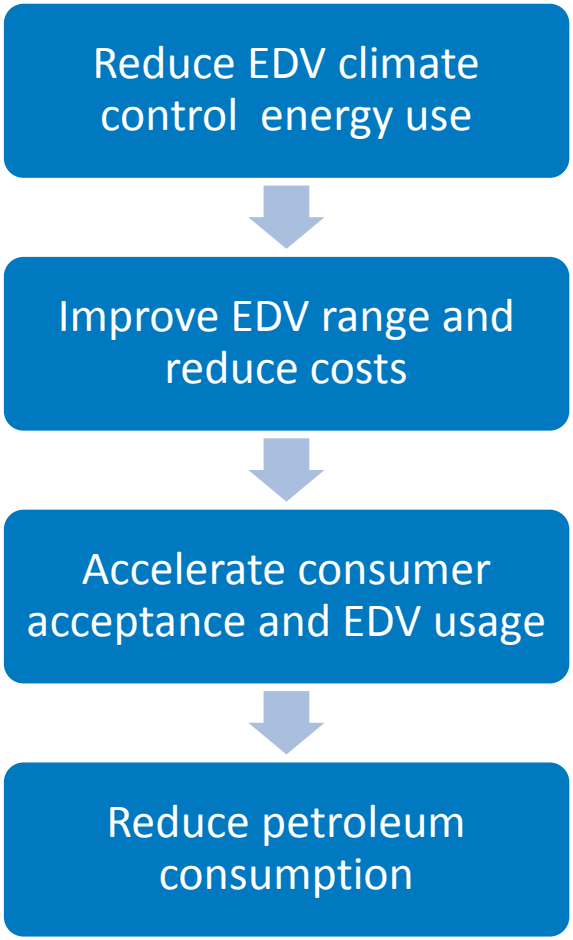
Future Work



- **Remaining FY15**
  - Determine driving range impact of zonal heating from cold weather test results.
  - Continue thermal analyses for heating conditions.
  - Calculate expected impact on range for a typical EV in the United States.
  - Compare test and analysis results against project target of 10% range improvement.
- **Project is scheduled to conclude after FY15.**

Summary

DOE Mission Support



Collaborations

- Automobile manufacturer
- Automotive Tier 1 suppliers
- Software developers
- National laboratories.

Summary – Technical Accomplishments

- **Advanced glazing and pre-ventilation can significantly reduce soak temperatures, saving energy during cool-down.**
- **A thermal manikin was utilized to demonstrate zonal cooling techniques to decrease A/C loads without sacrificing occupant comfort.**
  - 0.58 kWh (45.5%) saved with driver-only vent configuration (using existing air ducts and vents)
  - 0.92 kWh (66.5%) saved with combined TLR and zonal strategies.
- **Autonomie modeling shows potential improvement in EV range over Baseline A/C:**
  - 11% to 32% with combined strategies (TLR + overhead A/C).
- **Zonal heating has the potential to decrease warm-up time and save energy during transient heating.**
  - Up to 0.34 kWh (28.5%) less heating energy using driver-focused air flow and heated surfaces.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

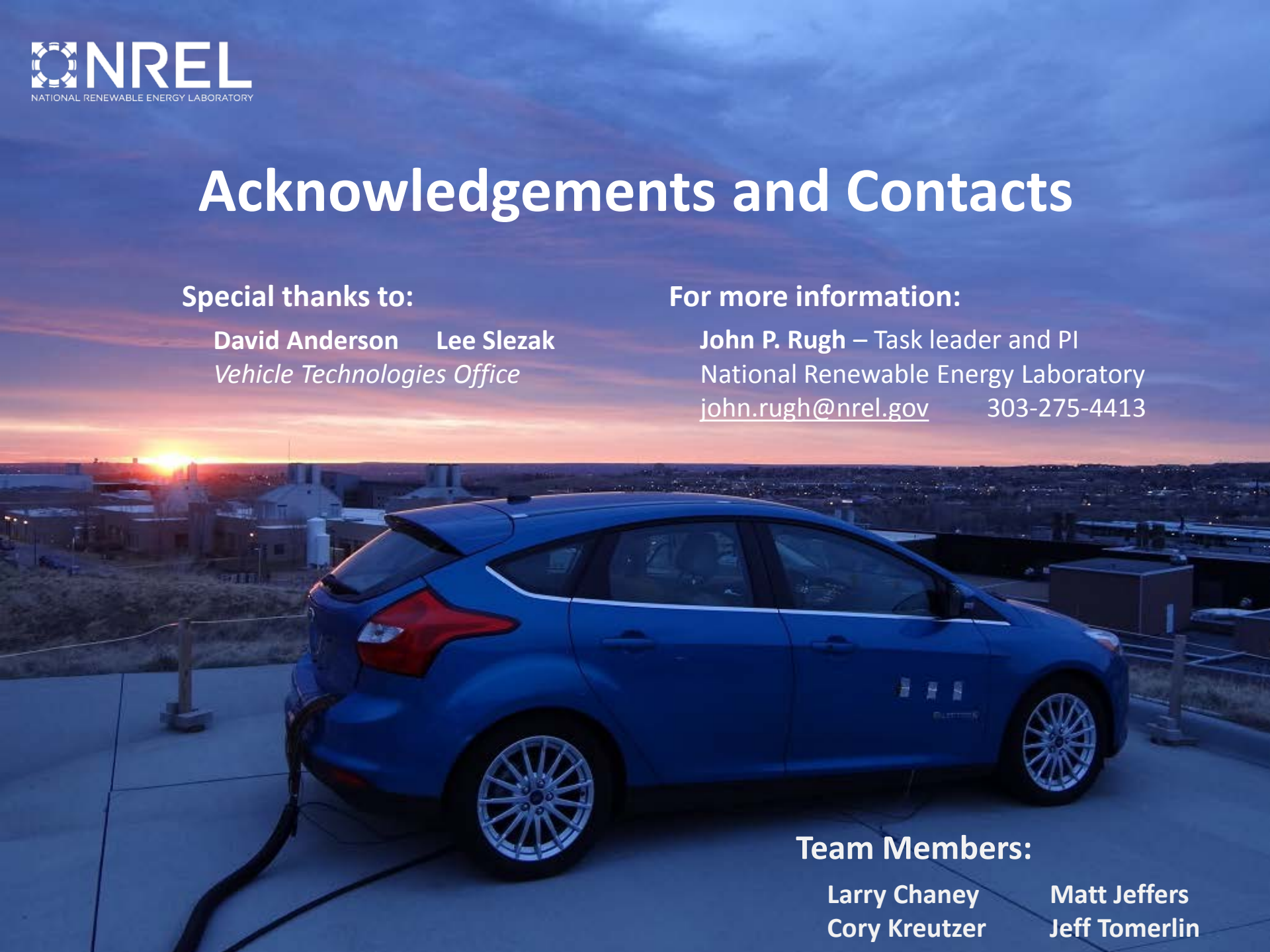
Acknowledgements and Contacts

Special thanks to:

David Anderson **Lee Slezak**
Vehicle Technologies Office

For more information:

John P. Rugh – Task leader and PI
National Renewable Energy Laboratory
john.rugh@nrel.gov 303-275-4413



Team Members:

Larry Chaney **Matt Jeffers**
Cory Kreutzer **Jeff Tomerlin**

Responses to Previous Year Reviewers' Comments

Reviewer Comments	Response
Reviewer said it was not clear in each case if the temperature reduction was a significant improvement in performance.	This was addressed in round two of summer testing this past year; cool-down tests were completed to quantify the A/C energy savings resulting from thermal soak temperature reductions.
Reviewer noted that rating climate control system performance can be subjective and asked about diversity in the test group of participants.	Engineering evaluation was used for heating tests because the thermal manikin used at the time was unable to measure the impact of heating through contact surfaces; our collaboration with industry partners has contributed to improved thermal comfort tools to overcome this limitation.
Reviewer found the project target of 10% range increase to be insufficient in magnitude to overcome range penalty of 20%–40% due to climate control loads; technical barrier needs to be matched with equally ambitious goals.	Setting an improvement target that completely eliminates the range penalty suggests that no energy would be used for heating/cooling, which is unrealistic; a 10% increase is a significant, yet achievable, improvement, but the overall goal is always to minimize climate control loads, striving for greater than 10%.

Photo Credits

Slide 1	Matt Jeffers, NREL
Slide 3	Matt Jeffers, NREL
Slide 5	Matt Jeffers, NREL
Slide 6	Matt Jeffers, NREL
Slide 8	Matt Jeffers, NREL
Slide 9	Josh Bauer, NREL
Slide 10	Matt Jeffers, NREL
Slide 11	Matt Jeffers, NREL
Slide 13	Matt Jeffers, NREL
Slide 16	Matt Jeffers, NREL
Slide 26	Matt Jeffers, NREL